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ORIGINAL RESEARCH ARTICLE

# SHEAR WALL PROVISION INFLUENCE ON MEDIUM RISE MULTI-STOREY FRAMED BUILDING IN MAIDUGURI

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**ABSTRACT**

This study compares the aerodynamic behaviour of medium rise multi-storey frame structures with and without shear walls using the local wind gust of Maiduguri (47m/s) as primary data. The wind assessment was carried out in accordance with recommendations of British Standard and other relevant specifications. Analysis of the structural system was carried out using Extended Three-dimensional Analysis of Building System (ETABS) software; where the forces, maximum floor drifts and stresses are obtained and compared. The result shows that, the displacement fora 15 storey building with shear wall was 91.44% less than same without shear walls while with increasing storey height, the differences reduce; for example, the displacement for 20 storey building with shear wall showed 81.5% lesser than same building without shear wall. This signifies that building with shear wall resist aerodynamic load more efficiently principally due to the influences of the rigidity and strategic locations of the shear wall in the building. The shear walls are usually effective in stabilizing displacements on medium rise multi-storey buildings subjected to lateral forces from wind, seismic and explosive to satisfy serviceability criteria of H/500 stipulated by most conventional standard..



## 1.0 Introduction

Wind is a phenomenon of great complexity because of the many flow situations arising from the interaction of wind with structures and the shear drag with the ground roughness. The significance of turbulence is that dynamic loading on a structure depends largely on the size of eddies generated along the height. The gustiness is strong at the lower levels of the atmosphere due to shear drag with features such as hills, grasses, trees and buildings. The average wind speed over a period of time in the order of 10minutes or more tends to increase with height, while the gustiness tends to decrease with height (Haritos et al., 2007). Structural gustiness decreases with height but vibration increases; therefore, gustiness and vibration are inversely proportional with respect to height (Mendis, et al., 2007).

Multi-story buildings shear walls are often incorporated at strategic locations to ensure adequate stiffness to resist lateral forces induced by wind or earthquakes. The walls may be placed in the form of elevator cores, enclosed stairways, shear boxes or facade walls. Such systems may be constructed in steel or concrete and may be either solid or perforated (couple shear walls). Normally, shear walls are designed to resist lateral forces while the frame is assumed to carry vertical loads. Columns, of course, also resist lateral forces, their contribution depending on their stiffness relative to the shear walls (Houssam, 1997).

Shear walls provide full resistance to horizontal loadings. They are usually continuous from the top floor down to the base where they are rigidly fixed to form vertical cantilevers. There high in plane stiffness and strength make them well suited for bracing building up to about 35 stories, while simultaneously carrying gravity loading (Smith and Coull 1991).

The types of forces resisted by shear walls are two; these are shear and uplift forces. Shear forces are generated in fixed buildings by motions resulting from ground movement and by external forces like wind. This action creates shear forces throughout the height of the wall between the top and bottom shear wall connections. Uplift forces however exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to overturn the wall over. Appropriate anticipation of wind effects is an important aspect of successful multi-storey building design. By providing shear wall in some frames, the top deflection was reduced to permissible deflection. Additionally, both bending moment and shear force in some frames are significantly reduced with the provision of shear wall (Anshuman et al., 2011).

Lateral displacement and inter-story drift was studied on a square symmetric structure with walls at the Centre and by the edges, and found that the presence of shear wall can affect the seismic behaviour of frame structure to a large extent this is true, because the shear wall increases the strength and stiffness of the structure the shear wall increases the strength and stiffness of the structure (Shahjad et al., 2013). Similar study was conducted by Rasikan and Rajendra (2013) that showed the displacements of multi-storey buildings with shear walls were 20% and 15% less than that without shear walls for 15 and 20 stories respectively but with the use of Staad Pro software. This shows the effectiveness of shear wall system is more economical for multi-story height (Chnadurkar et al, 2013 and Shahzad and Umesh, 2013).

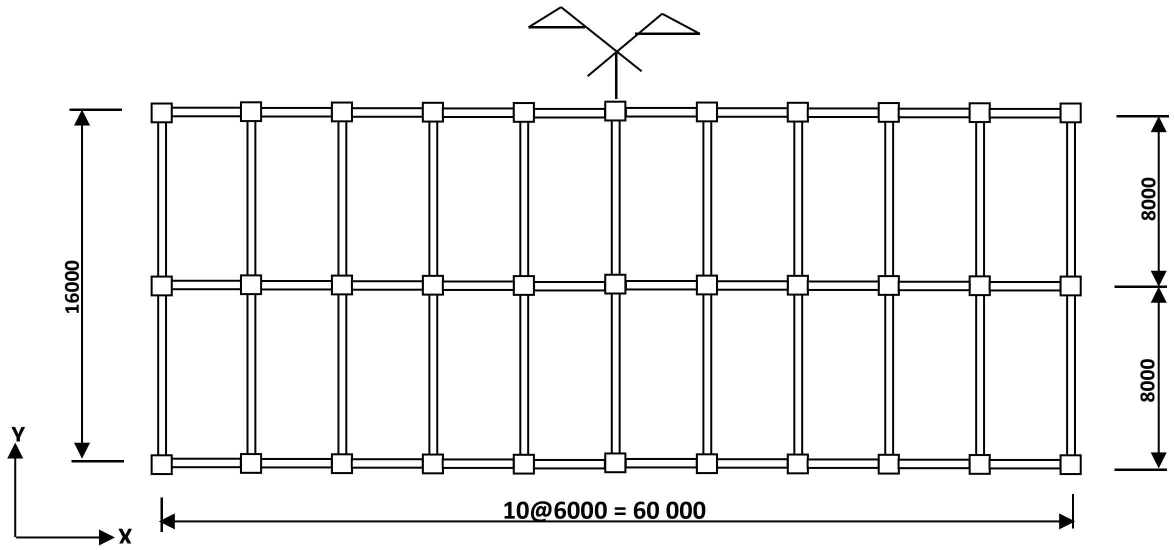
From the foregoing, it is seen that shear wall systems are one of the most commonly used lateral-load resisting systems, which have very high in-plane stiffness and strength, which can be used to simultaneously resist large horizontal loads and support gravity loads, making them quite advantageous in many structural engineering applications. Hence, this study compares the behavior of medium rise building (with and without shear wall) subjected to local prevailing wind gust in Maiduguri. Since, when the buildings are tall, deflection is major problem as well as beam and column sizes that are quite heavy, with lot of reinforcement congestion at the joints and they are difficult to place and vibrate concrete at those places. The study objective is how viable a typical Maiduguri wind gust influence a medium rise building using Extended three-dimensional analysis of building system (ETABS).

## 2.0 Methodology

### 2.1 Building Model and Wind Load Estimation

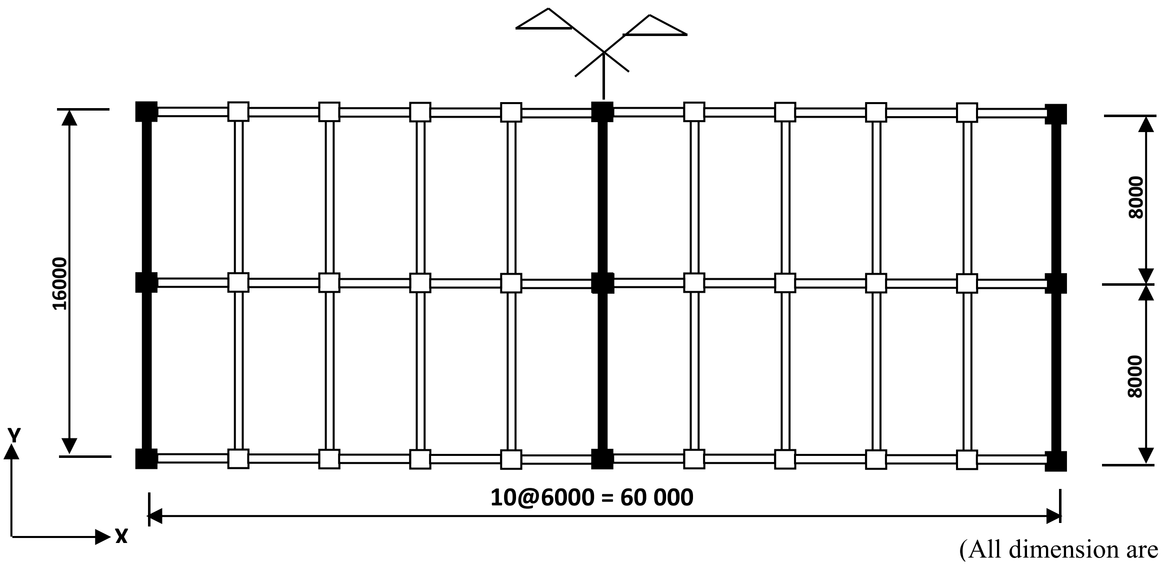
The buildings were assumed to be situated on a relatively flat terrain in an open area in Maiduguri, Borno state of Nigeria where they are exposed to winds gusting from all directions. The local prevailing wind speed of Maiduguri, category II, 100 year mean recurrent intervals is 47m/s (Onundi, 2010). The research studied two different model (15 and 20 storey medium rise buildings) with and without shear walls shown in Figures (1 and 2) respectively and in addition, compared their sway characteristics when subjected to aerodynamic loadings using ETABS software packages.

The horizontal load and forces generated by the local aerodynamic loading were in accordance with BS6399-2(2004) and literature recommendation (Onundi, 2010). The modelled reinforced concrete multi-storey buildings were 16m wide 60m long with a 45m for the 15 storey and 60m for the 20 storey heights respectively. The horizontal loads were resisted by eight (8) frames consisting of 8m two bays rigid frames interspaced at 3m centres and three (3) shear walls also positioned at 30m centres along the length of the building (Figures 1 and 2) respectively. Equations (1-4) BS6399-2 (2004) were used for the estimation of the equivalent wind loads (i.e. the external pressure total effect on the building for given axis).




(All dimension are in mm)

Figure 1: Structural Layout of the Model without Shear Walls




(All dimension are in mm)

Figure 2: Plan of the Building Structural Model with Shear Walls



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### 2.2 Wind Load Estimation

The procedure for the estimation of the characteristic wind load on the building was carried out in accordance with the specification of the BS6399-2 (2004) which is the code of practice for wind load. The code offers two alternative methods for determining the loads that the structure must with stand. For all structures where the wind loading can be represented by equivalent static loads, the wind loading can be obtained either by the standard or the directional method respectively. The Standard method uses a simplified procedure to obtain a standard effective wind speed, which is used with standard pressure coefficient to determine the wind loads for orthogonal design cases. Whereas the Directional method derives wind speeds and pressure coefficient for each wind direction, either orthogonal or oblique. In both methods, the dynamic wind pressures qs is calculated according to clause 2.1.2of the code (BS6399-2 2004).

For buildings that are at most slightly dynamic, (i.e. Cr< 0.25 and H <300 m, as is this case of study), The dynamic wind pressure according to (BS6399-2 2004) is given by:

$$q_s = 0.163\,V_e^2 N/m^2 \quad (1)$$

$$V_e = V_s \text{ x } S_b \quad (2)$$

$$V_s = V_b \text{ x } S_q \text{ x } S_d \text{x } S_s \text{x } S_p \quad (3)$$

where:

$V_e$= effective wind speed, $V_s$ = the site wind speed, $V_b$ = the basic wind speed, $S_a$ = the altitude factor, $S_d$ = the direction factor, $S_s$ = the seasonal factor, $S_p$ = the probability factor and Sb = the terrain factor, $C_r$=Dynamic augmentation factor

The internal and external pressures that are applied to the structure are calculated from the generic expression of clause 2.1.3.2 (BS6399-2 2004).

$$P = q_s C_p C_a \text{ x } A = 0.85 q_s C_a (C_{p,wind} + C_{p,lee})(1 + C_r) \text{ x } A \quad 4$$

where:

P = either the internal or external applied pressure (kN/m$^2$), $C_{pi}$= the internal net pressure coefficient or $C_p$, wind=Wind ward, $C_{pe}$= the external net pressure coefficient or $C_p$, lee-Lee ward, $C_a$= the size effect factor for either internal or external pressures, $C_r$= dynamic augmentations factor and A=Site exposure type, A= Area of the building exposed to wind

### 2.3 Analytical Example (Analysis Procedure)

The ETABS three dimensional models of 15 and 20 storey buildings without shear wall (Figures1) and with three shear walls (Figure 2) were evaluated using preliminary geometrical dimension and properties of the structures table 1.

Table 1: Geometrical dimensions and Properties of the Structures

| Geometrical Properties | 15 Storey | 20 Storey |
|---|---|---|
| Number of storey of the building model | Fifteen (G+14) | Fifteen (G+19) |
| Shear wall thickness | 150 mm | 150 mm |
| Grade of concrete and steel | C25/30 and Fyk 415 | C25/30 and Fyk 415 |
| Size of beam | 300 x 500 mm | 300 x 600 mm |
| Size of column | 300 x 600 mm | 350 x 600 mm |
| Slab thickness | 150mm | 150mm |
| Location | Maiduguri | Maiduguri |

## 2.4 Design Assumptions

Dead Load (DL) and Live load (LL) complied with the requirements of BS 6399-Part 1 (1996) and BS 8110-Part 1(1997); whereas, the wind load calculation was as per BS 6399-Part 2 (2004) respectively.

| | |
|---|---|
| Loads | |
| Live Load | 3 kN/m$^2$ |
| Floor Finishing | 1 kN/m$^2$ |
| Wind load and coefficients | |
| Wind Speed | 47m/s |
| Terrain Category | 2 |
| Structure Class | B |
| Risk Coefficient(k1) | 1 |
| Topography(k3) | 1 |

**Material Properties**

The materials and their general properties are:

| Materials | Properties |
|---|---|
| Material Type | Concrete C25/30 |
| Unit weight | 24.993kN/m$^3$ |
| Mass per Unit Volume | 2548.538 kg/m$^3$ |
| Modulus of Elasticity | 31000 MPa |
| Shear Modulus | 12916.67 MPa |
| Poisson's Ratio | 0.2 |
| Coefficient of Thermal expansion | 0.00001 1/C |

## 2.5 Load Combinations

Load combination and the distribution of those loads on various components of the structure like Frame network (beams, columns, slabs) and shear walls are of critical primary importance to the design of structures. These are obtained by multiplying the characteristic loads by appropriate partial factors of safety, (BS 2.4.1.3). For example, if a structure is subjected to dead load (DL) and live load (LL) only, the design will need only one loading combination, namely 1.4DL+ 1.6 LL. However, in addition to the dead and live loads, if the structure is subjected to wind (WL) and/or earthquake (EL) loads, and considering that these loads are subject to reversals actions; the following load combinations for ultimate limit state might have to be considered (BS 2.4.3):

| | |
|---|---|
| 1.4 DL | |
| 1.4 DL + 1.6 LL | (BS 2.4.3) |
| 1.0 DL ± 1.4 WL | For Wind load (BS 2.4.3) |
| 1.4 DL ± 1.4 WL | |
| 1.2 DL + 1.2 LL ± 1.2 WL | |



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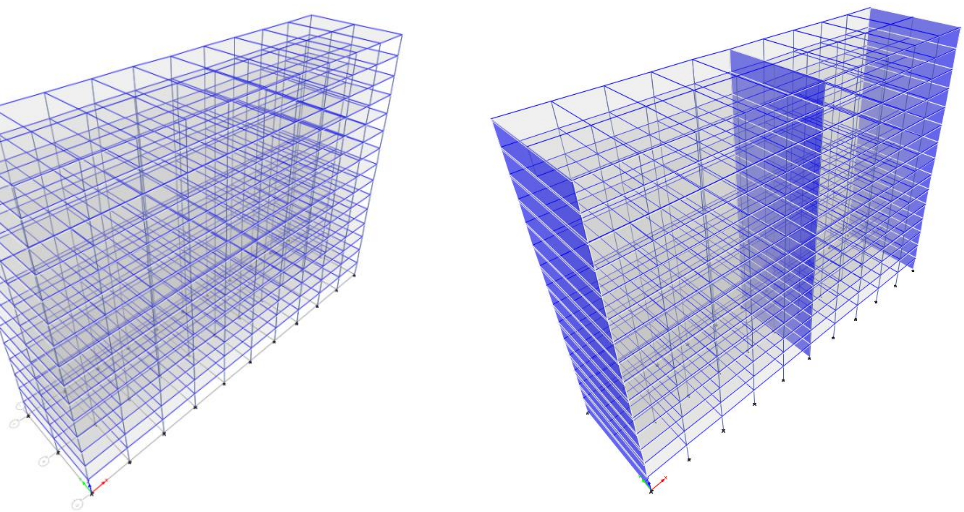
## 2.6 ETABS Analysis

The 3D medium rise building models were modelled and analysed as Equivalent Static Method (Clause 1.6, BS 6399-2) using ETABS 2013 software. Parameters such as storey maximum/average displacement, maximum shear force, axial force and maximum bending moment were calculated for the building models (Building with shear walls and without shear walls, Figure 3).



a) Building without Shear Walls (b) Building with Shear Walls

Figures 3: Typical ETABS model of the Multi-storey Buildingswith and without Shear Walls

## 2.7 Assessment of Human Perception Criteria

The human perception criterion is the evaluation given to the possible intensity of pulsation or sensation occupants are likely to feel when the multi-storey building is subjected to aerodynamic or seismic loadings. The perception criteria were therefore assessed by using the worst conditions of the coefficient for the characteristic mode of vibration as indicated by the equations (Onundi, 2011).

Displacement y, velocity v, acceleration a, limit and human comport assessment hca for the buildings were given by equations (5, 6, 7 and 8) respectively:

$$y = A \times \mathrm{Sin}(\omega t) \quad (5)$$

$$v = 0.101937\ (\omega A)\mathrm{Cos}\ (\omega t) \quad (6)$$

$$a = -0.010391\ (\omega^2 A)\ \mathrm{Cos}\ (\omega t) \quad (7)$$

$$h_{ca} = -0.0105923(\omega^2 A)\mathrm{Cos}(wt) \quad (8)$$

where, y = the maximum horizontal displacements in mm, A = Amplitude in mm,ω = Frequency in rad/sec, t = the period for vibration for the building in sec, g = acceleration due to gravity $m/s^2$ and hca = human comport assessment milli-g.

## 3.0 Results and Discussion

This study analysed3D models for the displacements for the buildings along major axes for structural elements of 15 and 20 storey reinforced concrete multi-story buildings subjected to the influence of prevailing wind speed for Maiduguri environment assessed with the recommendations of BS 6399 using the ETABS 2013 software. The parameters considered as critical were the maximum and average displacements, storey forces and moments, maximum base moments, support reactions and the variation of the displacements along the model heights. Hence, the computed medium rise buildings' displacement for both prevailing conditions are presented in Figure 4.

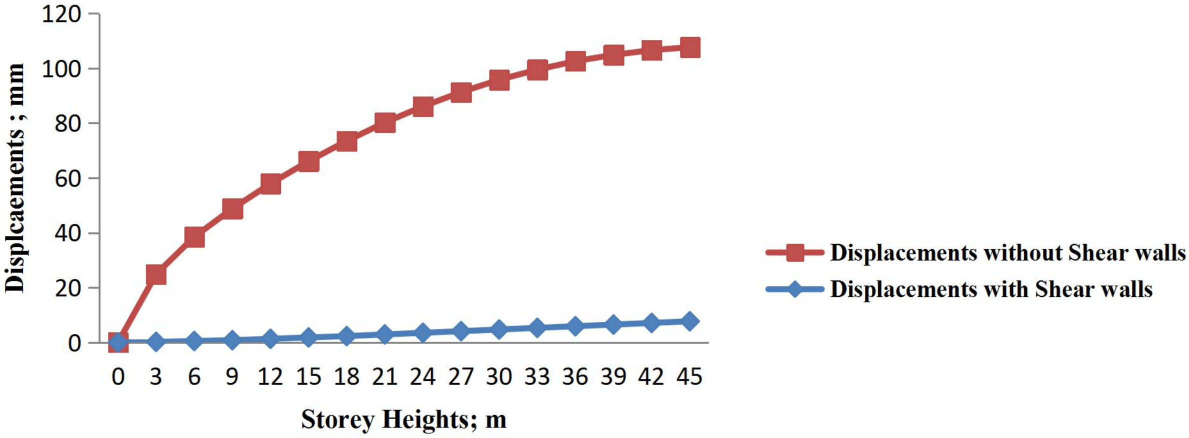



Figure 4a: Max. Displcements of a 15-Storey Building with and without Shear Walls

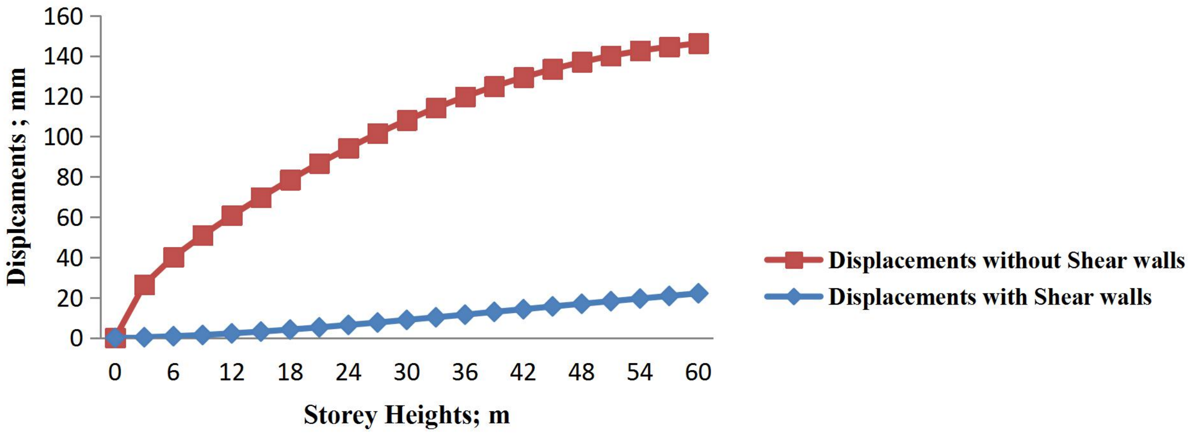



Figure 4b : Max. Displacements of a 20-Storey Building with and without Shear Walls

From Figures 4(a and b) and Table 2, were observed that the maximum top drifts or displacements of the 45m, 15 storey building without shear walls was 107.7mm which is 19.67% higher than the permissible serviceability limit state H/500 recommended by BS 8110 (1997), whereas, when compared with the result of the same building with three shear walls, only 7.7mm was recorded which is 91.44% less.

Similarly, the maximum top drifts or displacements of the 60m, 20 storey building without shear walls was 146.3mmwhich is 21.92% higher than the permissible serviceability limit state H/500 recommended by BS 8110 (1997) and (Abdur Rahman, 2012), whereas, when compared with the result of the same building with three shear walls, only 22.1mm was recorded which is 81.58% less which is obviously due to the influence of the lateral resistance offered by the shear walls and strategic location of the walls. These results are in consistent with the studies conducted by



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(Rasikan and Rajendran 2013) and (Anshuman et al., 2011) on comparative study on building with and without shear wall, and location of shear wall in building respectively.

Table 2: Models displacements and Limiting values

| Building Model | Top Storey Displacements without shear walls (mm) | Top Storey Displacement with Shear walls (mm) | Recommended limit | %Differences |
|---|---|---|---|---|
| 15 Storeys | 107.7 | 7.7 | 90 | 91.44 |
| 20 Storeys | 146.3 | 22.1 | 120 | 81.5 |

The evaluation of human perception criterion at the top of 15 and 20 storey buildings without and with shear walls are presented in Tables 3 and 4 respectively.

Table 3: - 15 - Storey modal frequencies, periods, acceleration, human perception limits

| Multi-Storey | Period | Frequency | Circular Frequency | Eigenvalue | Displacement | Amplitude | Velocity | Acceleration | Milli-g |
|---|---|---|---|---|---|---|---|---|---|
| | Sec | cyc/sec | rad/sec | rad²/sec² | Mm | Mm | mm/sec | mm/sec² | |
| Without Shear Walls | 3.48 | 0.288 | 1.81 | 3.28 | 107.70 | 984.12 | 181.80 | 33.58 | 34.23 |
| With Shear Walls | 3.37 | 0.297 | 1.86 | 3.47 | 7.70 | 70.37 | 13.37 | 2.54 | 2.59 |

Table 4 : 20-Storey modal frequencies, periods, acceleration, human perception limits

| Case | Periods | Frequencies | Circular Frequencies | Eigenvalue | Displacement | Amplitude | Velocity | Acceleration | Milli-g |
|---|---|---|---|---|---|---|---|---|---|
| | Sec | cyc/sec | rad/sec | rad²/sec² | Mm | mm | mm/sec | mm/sec² | |
| Without Shear Walls | 3.622 | 0.276 | 1.7345 | 3.0086 | 146.300 | 1336.949 | 236.386 | 41.795 | 42.607 |
| With Shear Walls | 3.703 | 0.27 | 1.6967 | 2.8789 | 22.100 | 201.942 | 34.927 | 6.041 | 6.159 |

Tables 3.0 and 4.0gives the acceleration and human perceptions criteria limits values, and this shows that the acceptable limit of 3% (30 milli-g) was exceeded of gravity for office buildings without shear walls and that was obviously due inadequacy of the frame alone to provide the necessary lateral resistance. this indicates the necessity of conducting detailed dynamic evaluation for wind tunnel as shown in literature (Taranath, 2010). however, the buildings with shear walls have satisfied these recommended limits. Generally, more stringent requirements are suggested for residential and hotel buildings, which would have continuous occupancy in comparison to office buildings usually occupied only part of the time and whose occupants have the option of leaving the building before there is windstorm.

## 4.0 Conclusion

In designing medium rise multi-storey buildings it is necessary not only to aim at, acquiring strength, safety and durability, but also to consider the necessity to provide adequate rigidity and serviceability criteria (comfort for occupants) due to excitation caused by the influence of lateral loadings as shear walls are often incorporated at strategic locations to ensure adequate stiffness to resist lateral forces induced by wind. Therefore, it can be concluded that:

Bending moments and shear forces were increased at the base (i.e. ground level) in moment frames after providing shear walls in 15 and 20 storey buildings respectively. It also inferred that, because of the rigidity; shear walls and the moment frames play important roles with respect to displacement at top floor of the buildings subjected to pulsating wind gust.

The limiting displacement (i.e. top drift) of H/500 is satisfactory taking into consideration the simultaneous frame and foundation rotation condition.

The rigidity and stability are vital and of significant importance to arresting the throbbing influences of wind load excitation mechanism in design of tall building. The human perception criterion limit is also within the permissible value of 30 milli-g when shear walls were provided in the buildings.

The limiting drift in the range of H/500 is satisfactory but more stringent value is recommended to take in to account super-structure /foundation rotation condition, which will help in achieving a better evaluation of deflection and other forms of dynamic loading.

Occupancy perception criterion level or motion of the building when subjected to the dynamic wind pulsation should be kept as low as 2% - 3% of gravity.

Wind tunnel analysis method is recommended for better understanding of the dynamic behaviour of structure's vibration and other serviceability criteria.

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